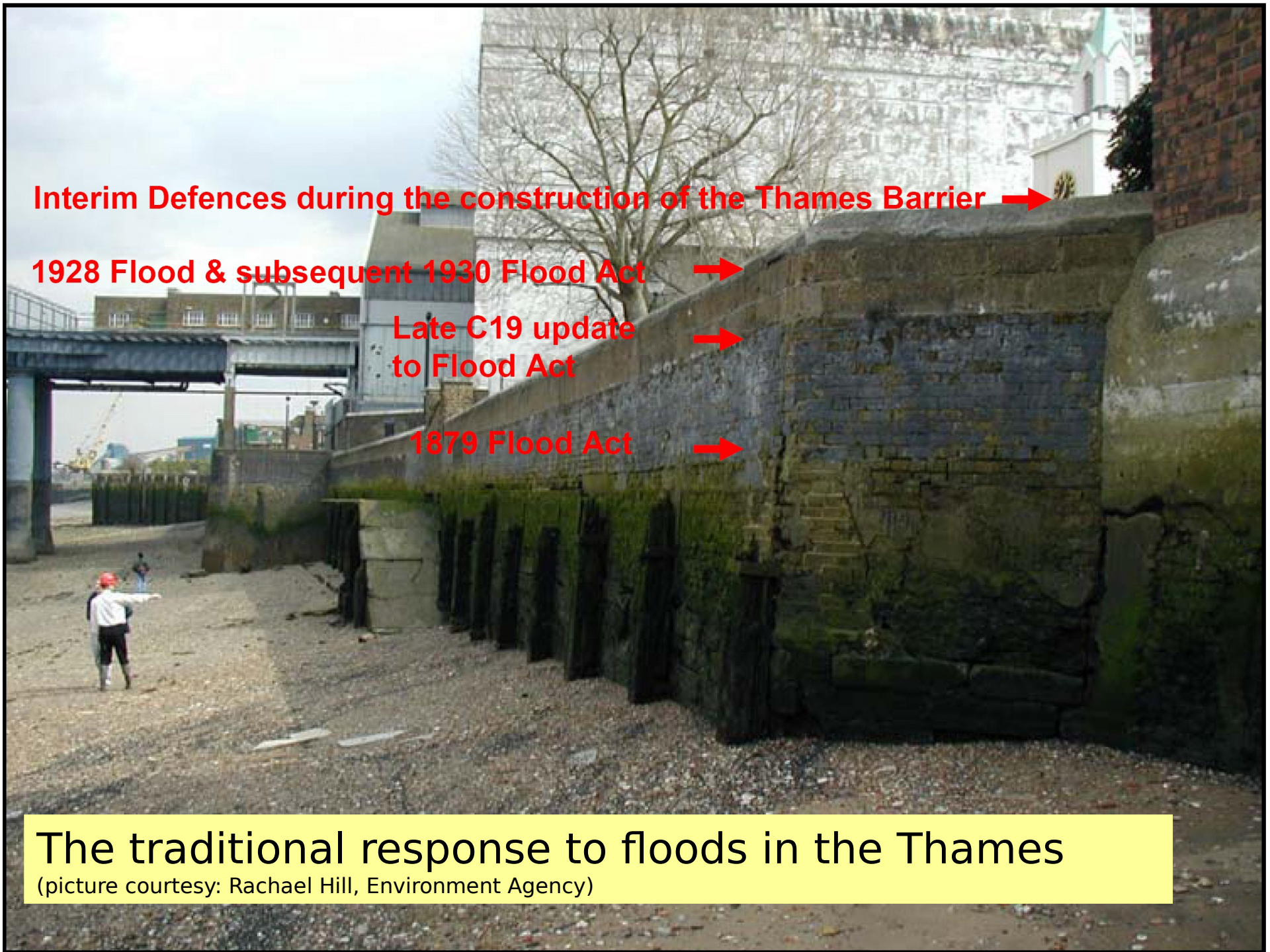
National-scale quantified analysis of future flood risk in the UK

Paul Sayers
Head of Floods and Water Management
HR Wallingford, UK

Jim Hall
Professor of Earth Systems Engineering
School of Civil Engineering and Geosciences
Newcastle University, UK


Interim Defences during the construction of the Thames Barrier
1928 Flood & subsequent 1930 Flood Act
Late C19 update
to Flood Act
1879 Flood Act

The traditional response to floods in the Thames

(picture courtesy: Rachael Hill, Environment Agency)

Contents

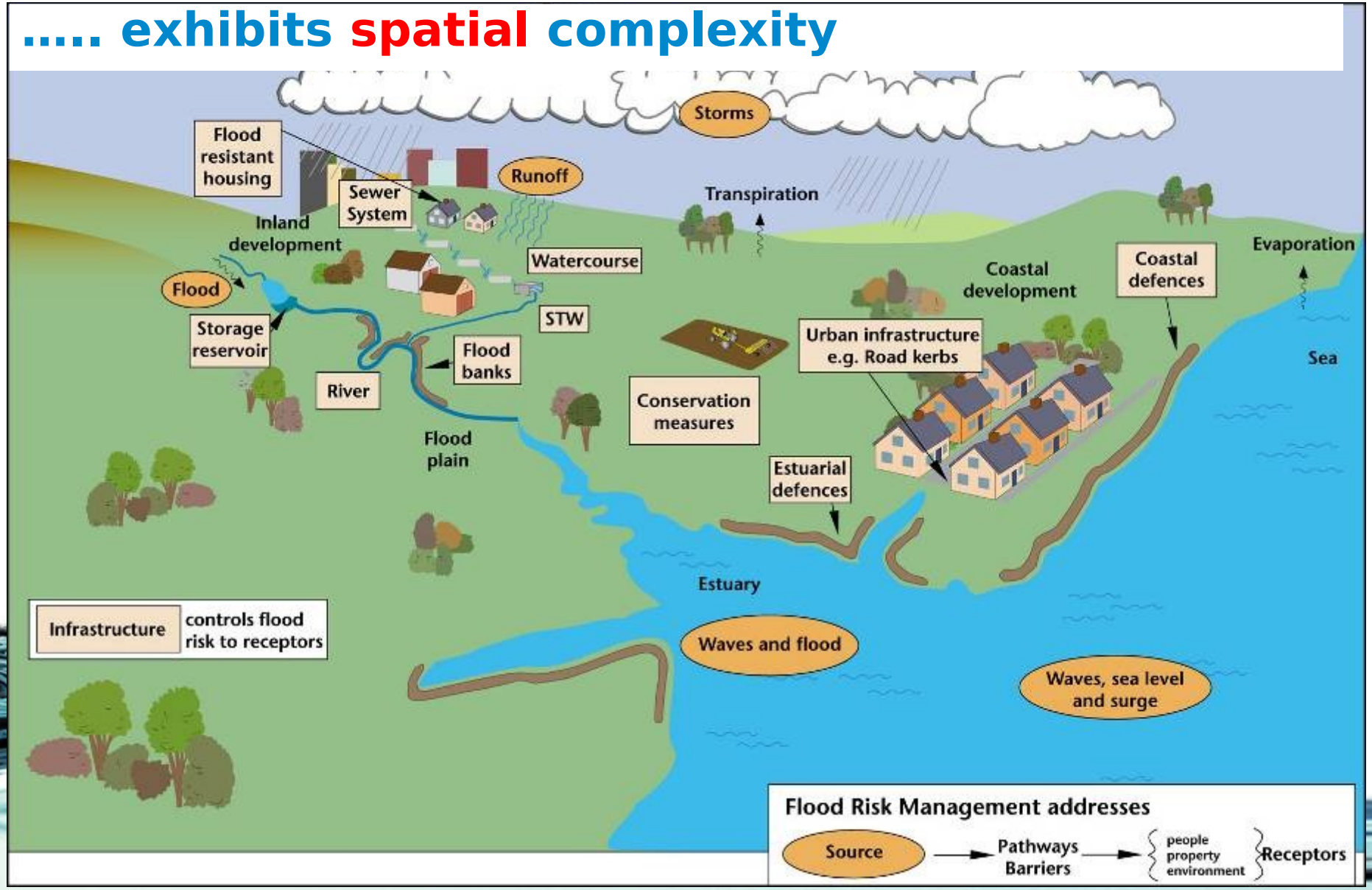
1. The principles of quantified flood risk analysis
2. National-scale flood risk analysis in the UK
3. Foresight analysis of scenarios of future change in flood risk
4. Foresight analysis of potential responses to changing flood risk
5. Approximate analysis of the costs of responding to flood risk

The aim of the quantified analysis

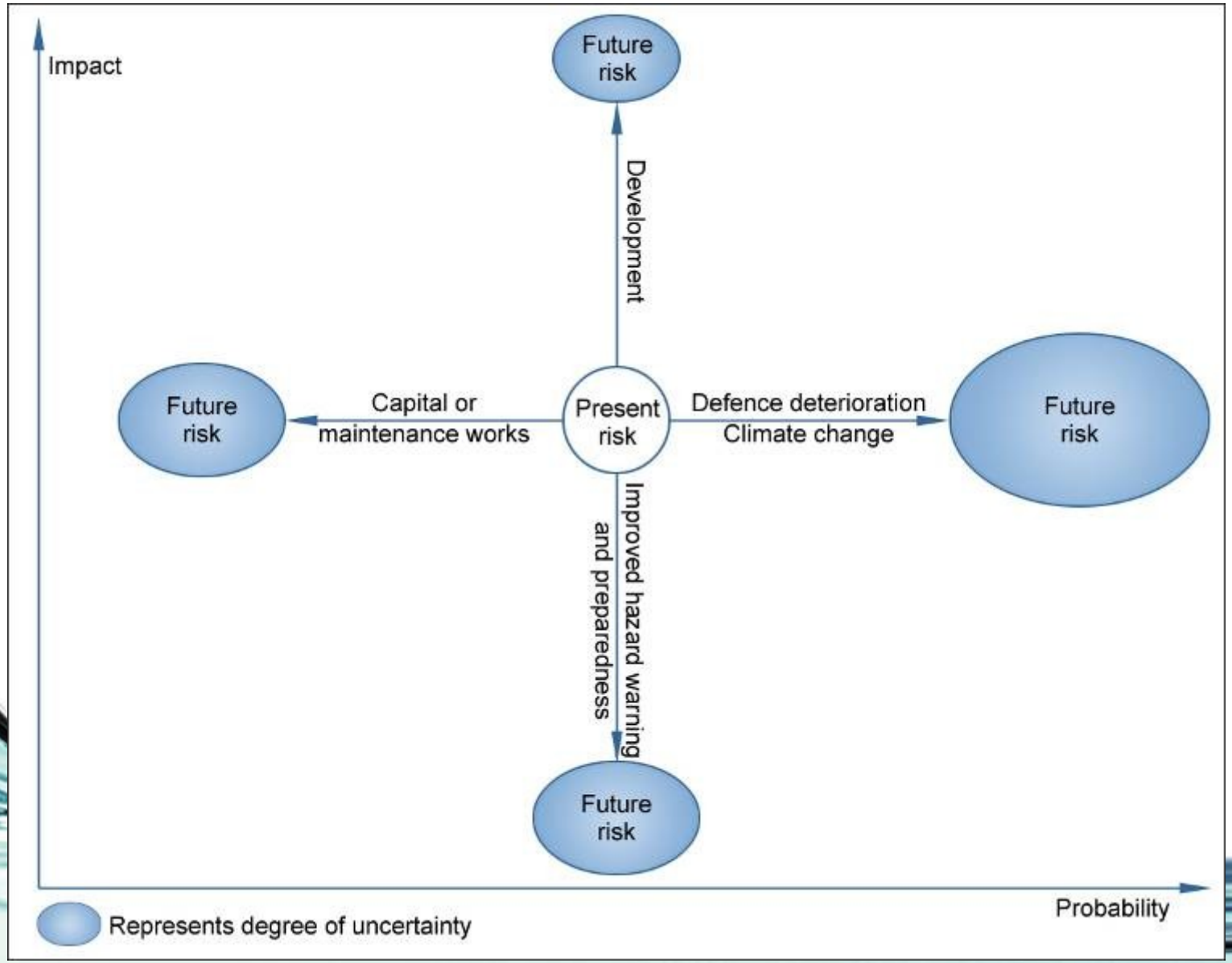
- To quantify Risk: f(Probability.Consequence)
- To differentiate **high** risk from **low** risk areas and its **change** in time
- To support the identification of the:
  - Most important factors influencing risk
  - Drivers of future change in risk
  - Most effective responses

The flood risk system

..... exhibits spatial complexity



And exhibits temporal change….



The RASP system risk model

Future Flooding

Utilises a structured definition of the flood system…….

Pathway

(e.g. beach, defence and floodplain)

Receptor

(e.g. people in the floodplain

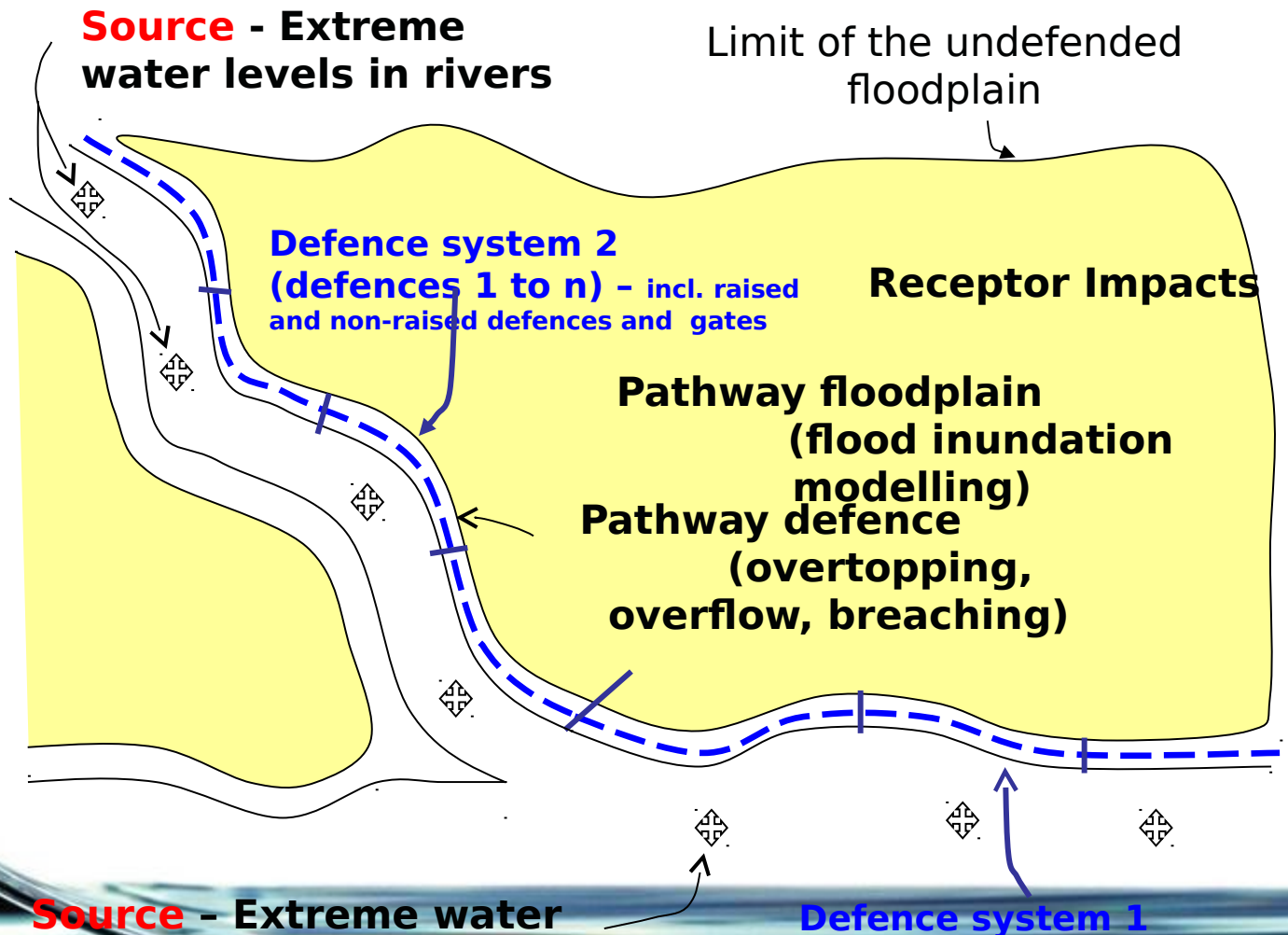
Source

(River or sea)

The system risk model

Future Flooding

Components of the RASP model…….

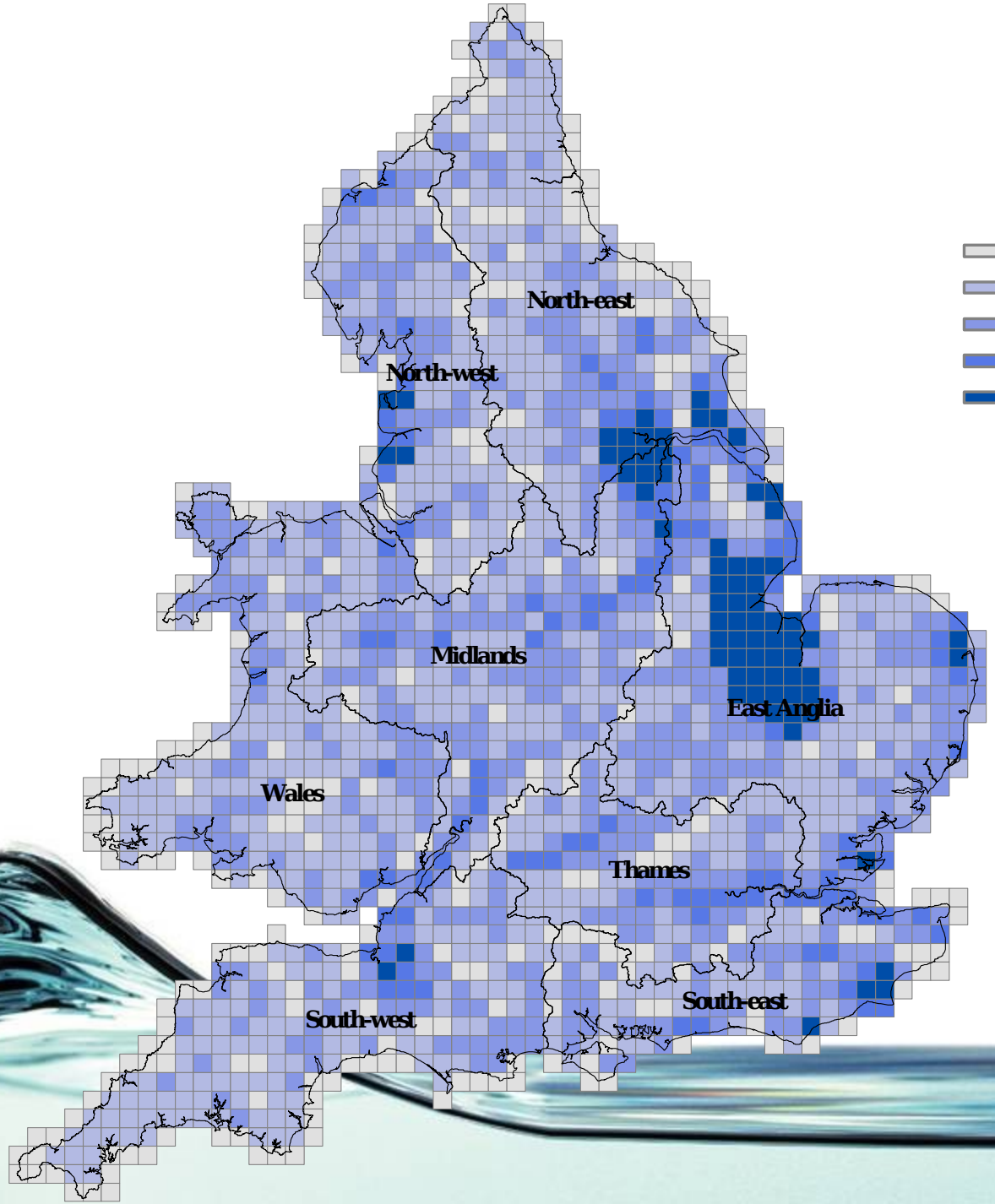

Source - Extreme water levels in rivers
Limit of the undefended floodplain
Defence system 2 (defences 1 to n) – incl. raised and non-raised defences and gates
Receptor Impacts
Pathway floodplain (flood inundation modelling)
Pathway defence (overtopping, overflow, breaching)
Source – Extreme water levels on coast
Defence system 1 (defences 1 to n)
incl. raised and non-raised defences and gates

Data used in national-scale analysis

Future Flooding

- Indicative Floodplain Maps (IFM)
- 1:50,000 maps with 5m contours (Composite DTM – 50m)
- National dataset of the centreline of all watercourses
- National Flood and Coastal Defence Database (35,000km of flood defences)
- National database of locations of residential and business properties (National Property Dataset)

Future Flooding



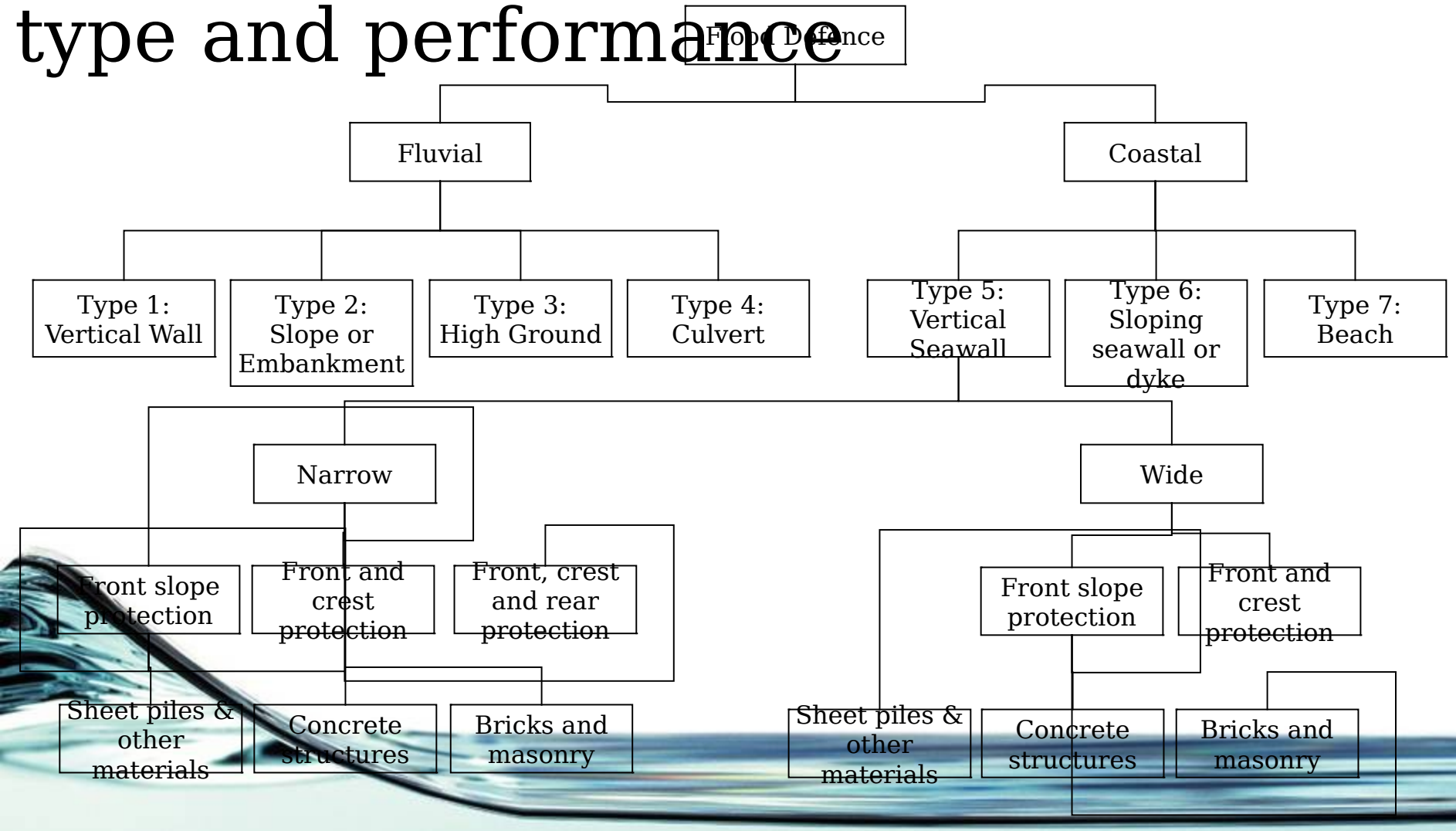
% IFP Class	Definition % area of 10km grid within the IFP
Negligible	<1%
Low	1-5%
Medium	5-20%
High	20-50%
Very high	>50%

Distribution of the "Indicative" Flood Plain 10km/6m x 10km/6m grid)

The system risk model

Future Flooding

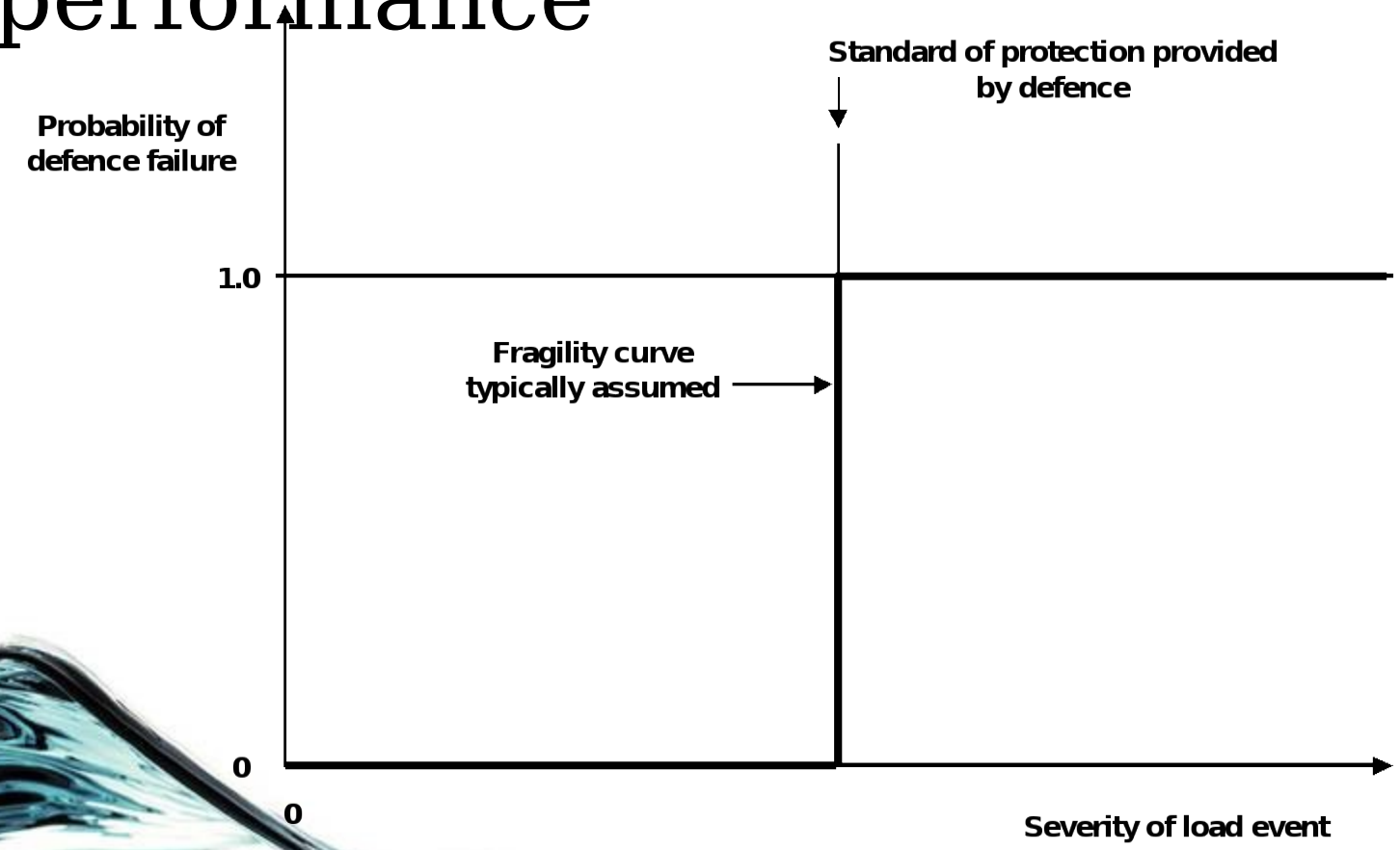
Board scale representation of levee type and performance



The system risk model

Future Flooding

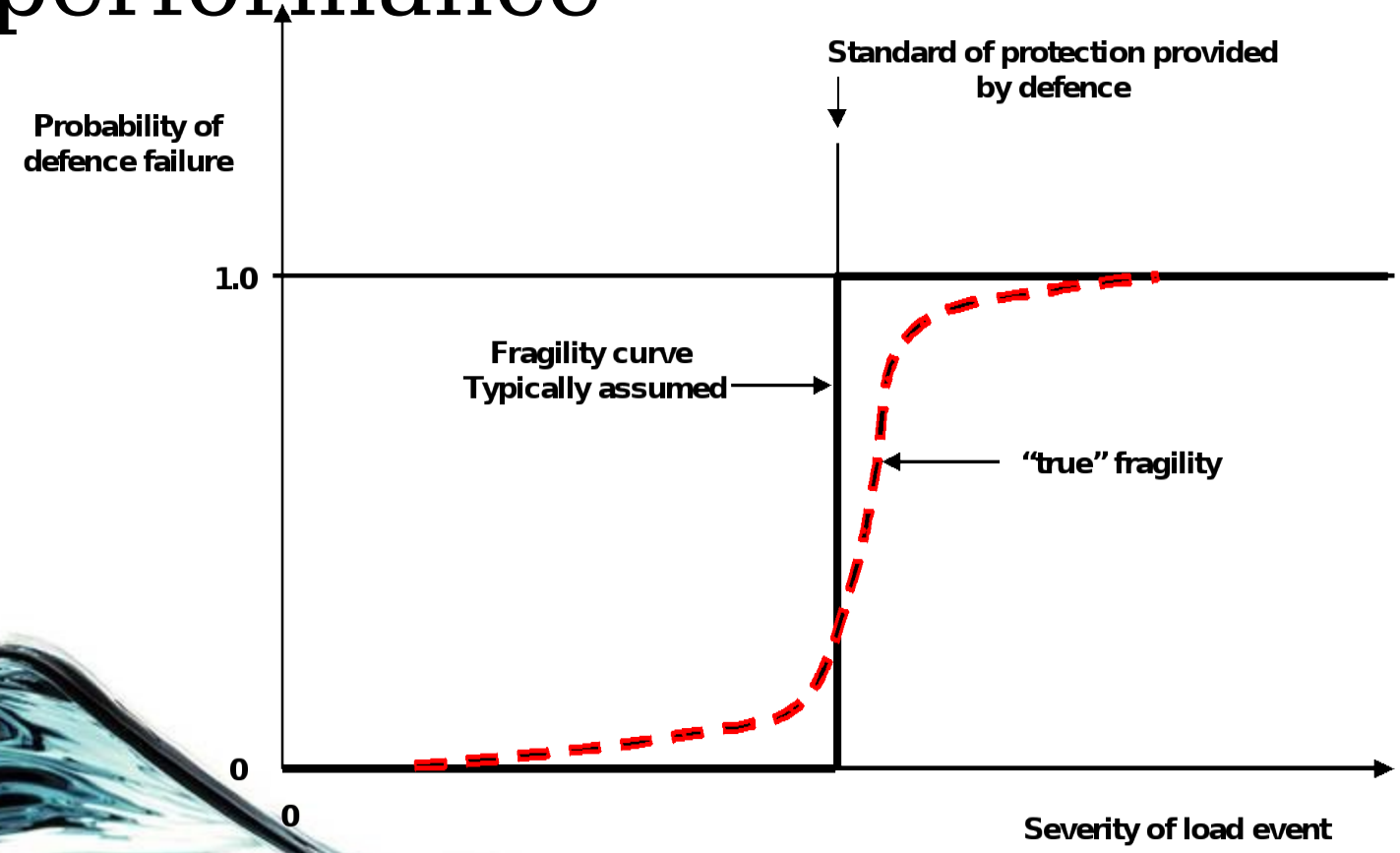
Representing levee performance



The system risk model

Future Flooding

Representing levee performance

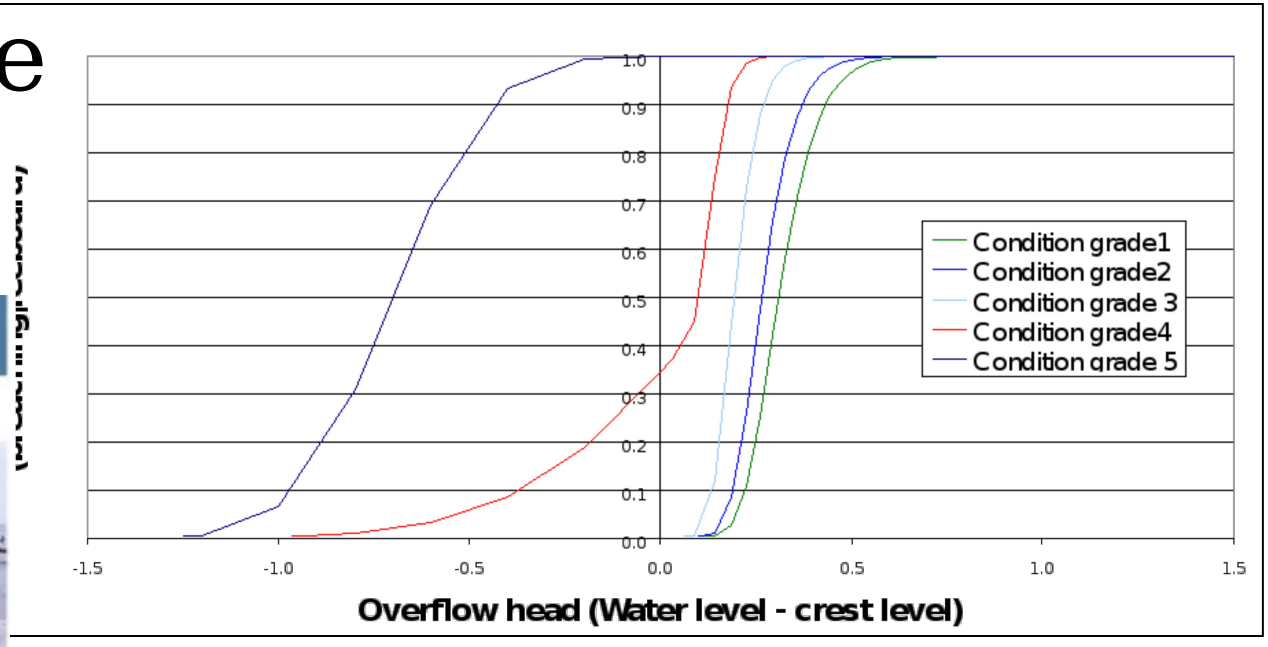


The system risk model

Future Flooding

Representing levee performance

Concrete Structures
Condition
Specific Description:
Completely derelict, structural failure or beyond repair. Concrete has failed and moved or completely collapsed. Considerable loss of wall thickness and reinforcement cover from shingle abrasion.
General:
Completely failed or derelict requires complete reconstruction. Major urgent repairs or replacement needed without delay to avoid failure. Probably beyond repair. Extensive defect, >50% of length or area affected.
2/15

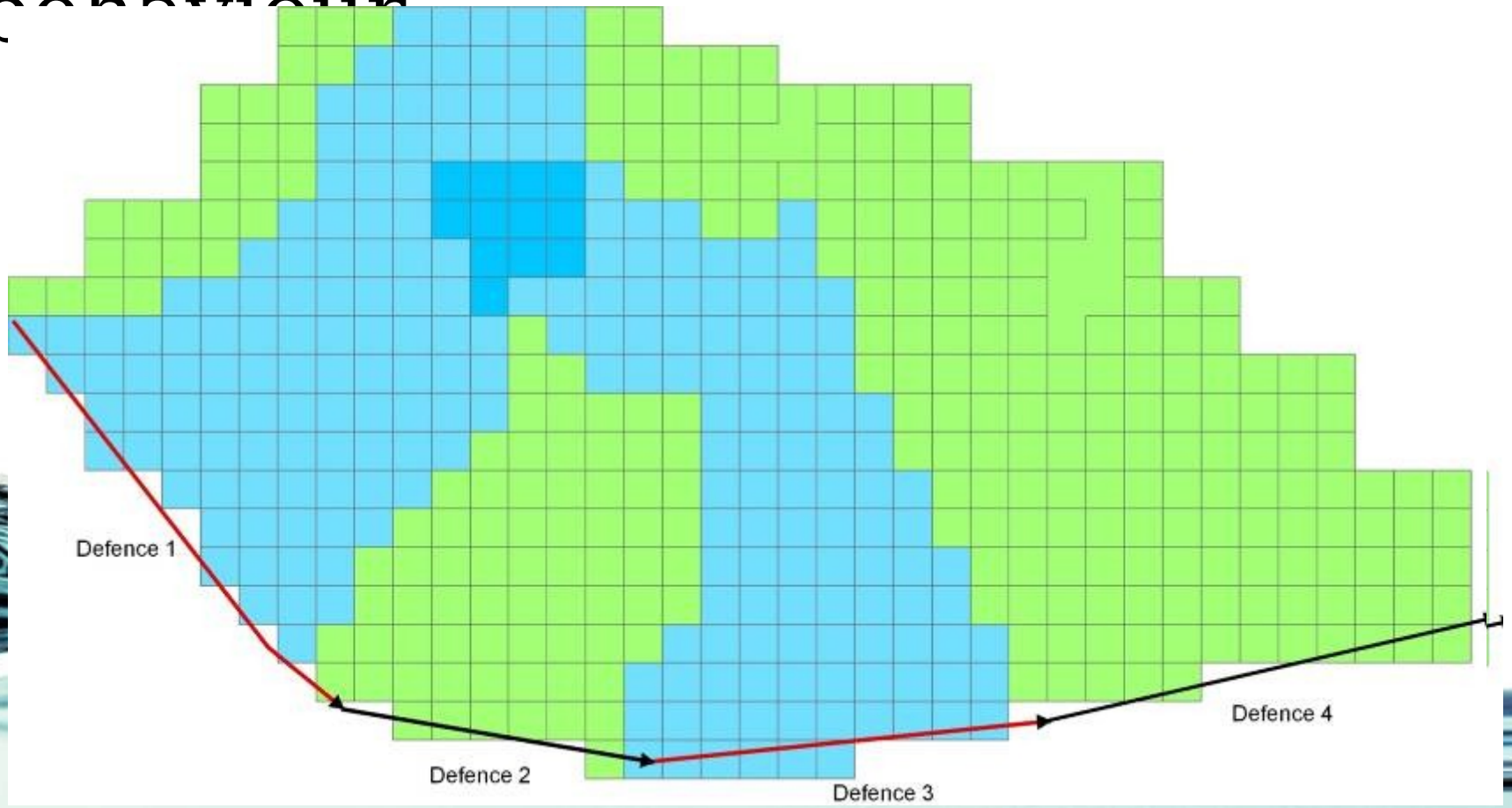


Limited no. of parameters in the NFCDD support the definition of a **High level** fragility curve
All sloping embankments

The system risk model

Future Flooding

Determining flood depth versus probability – accounting for system behaviour



The national system risk model

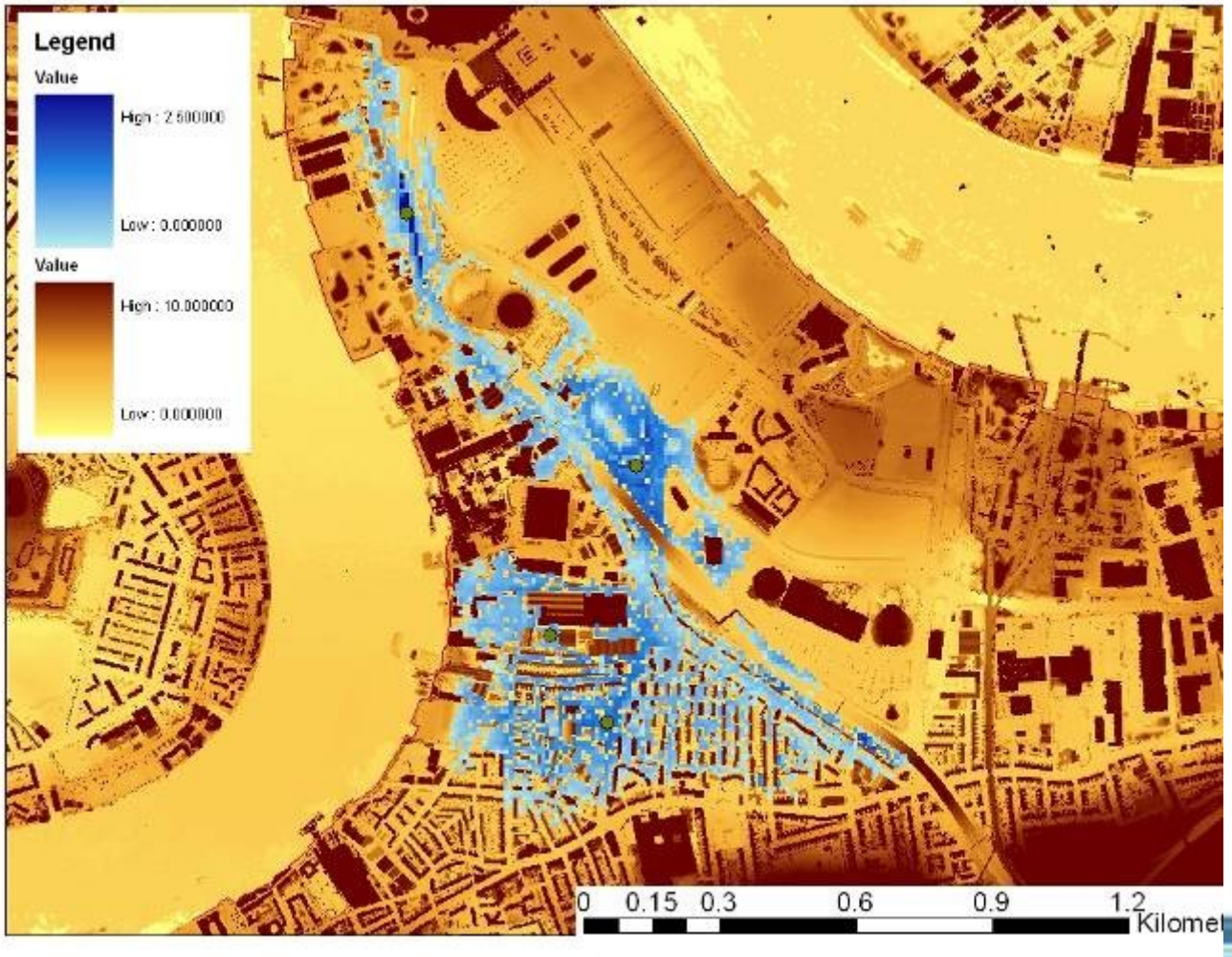
Future Flooding

Spreading flood water....

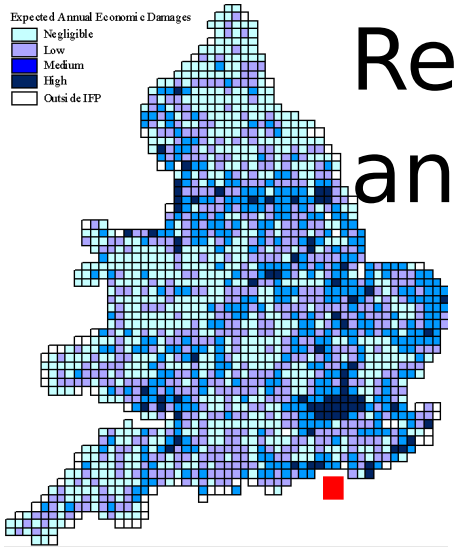
All inundation scenarios ***Foresight 02*** – we used a generalised statistical spreading technique...

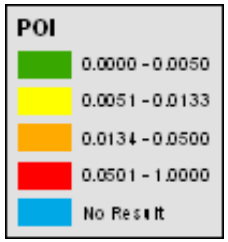
....more recently...

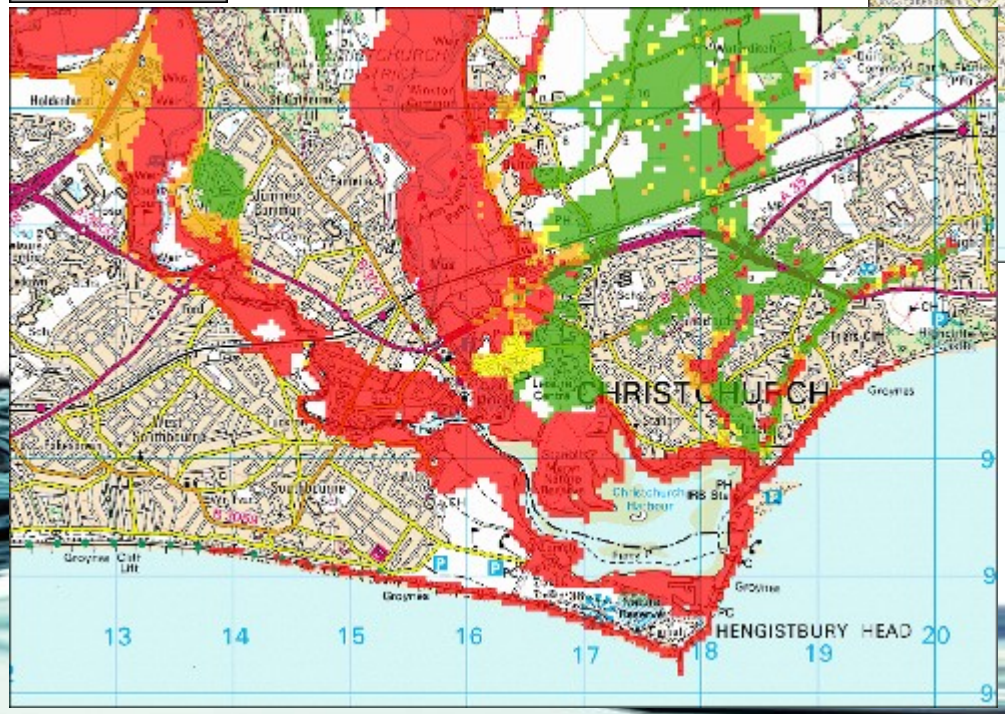
National flood risk assessment 2008 – we now use a physical based rapid spreading model (RFSM)



Results of national-scale analysis



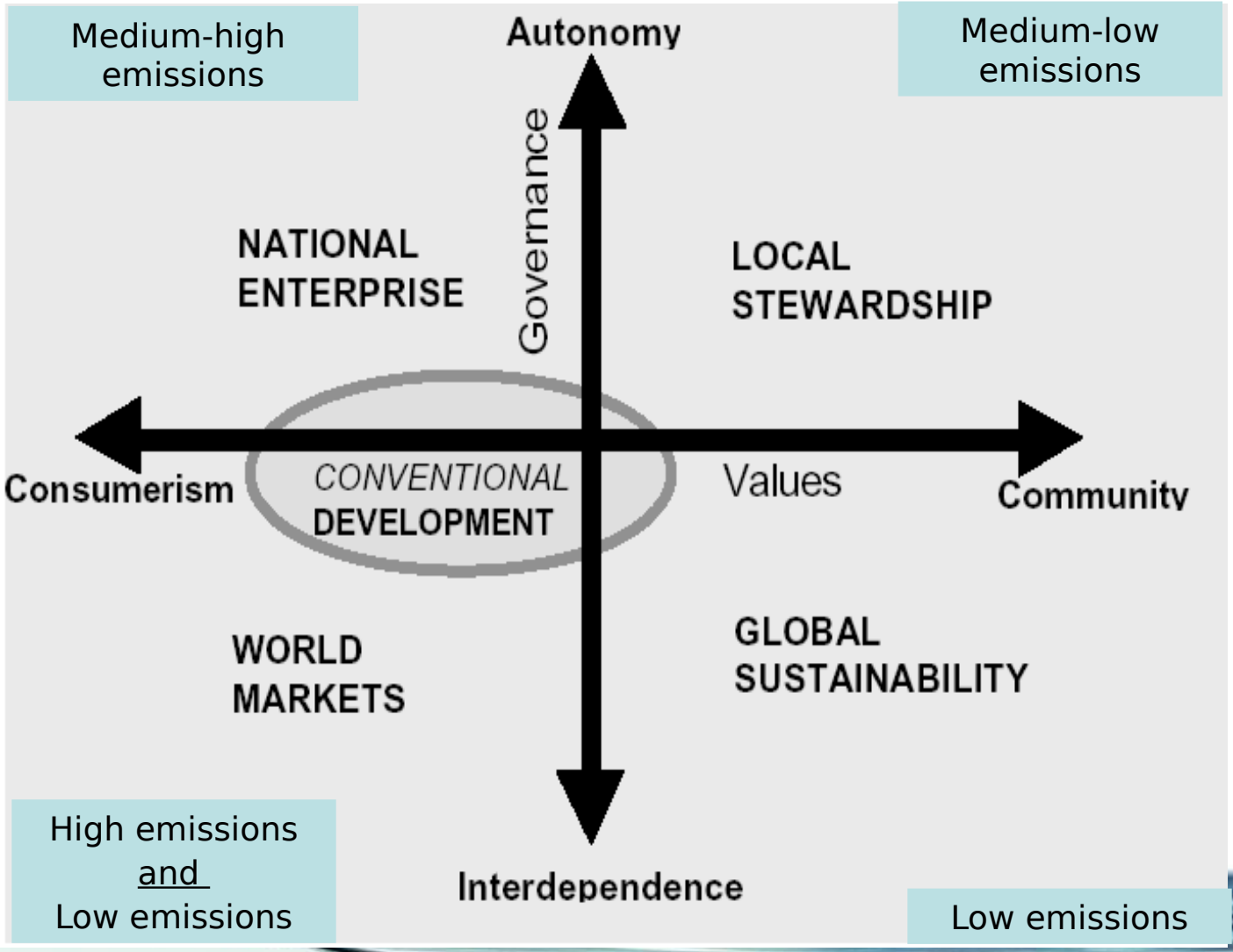


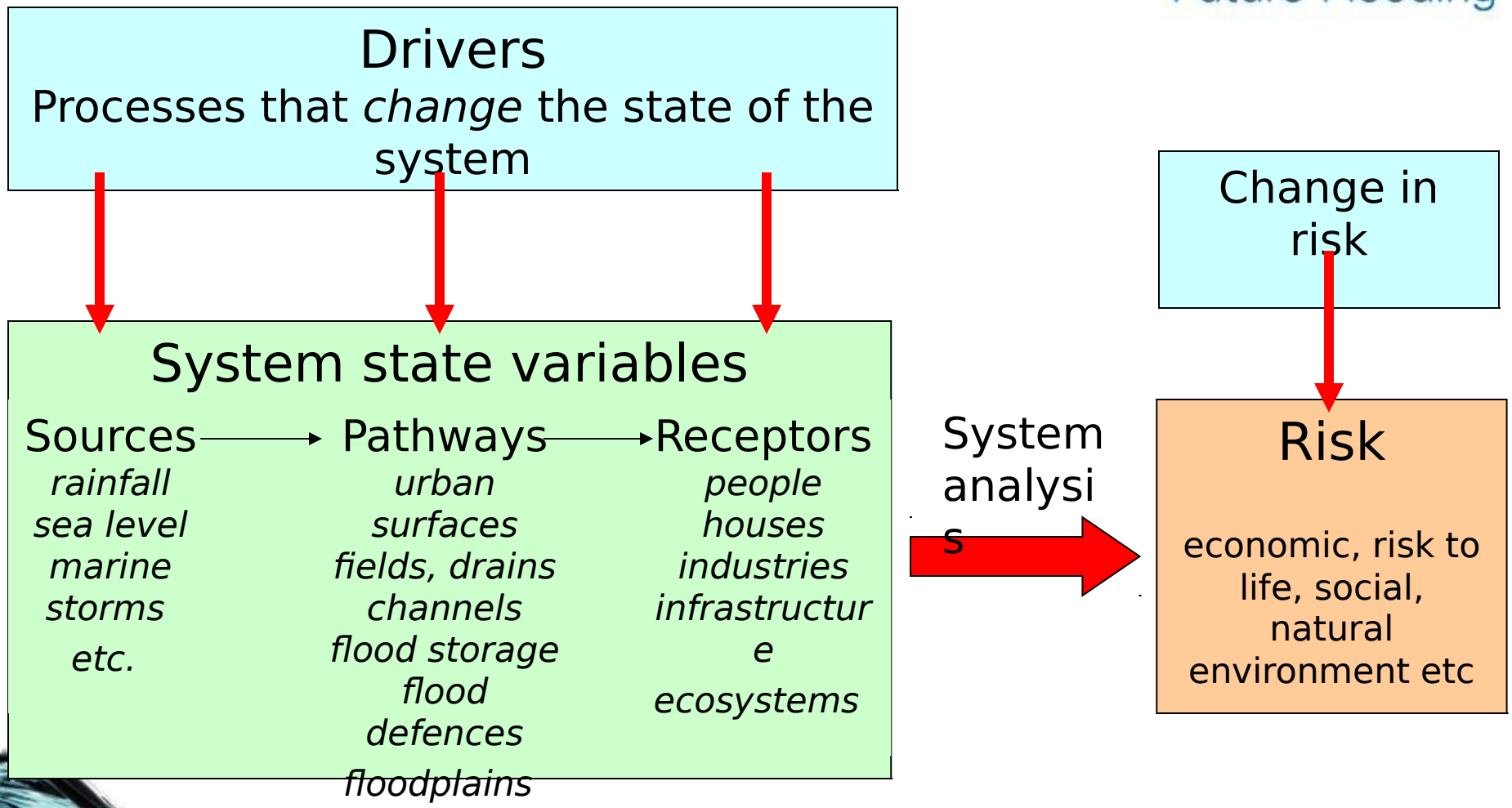


Example results from the national assessment 2008 (NaFRA, 08)

Foresight scenarios of future socio-economic change

Foresight Futures + climate change scenarios





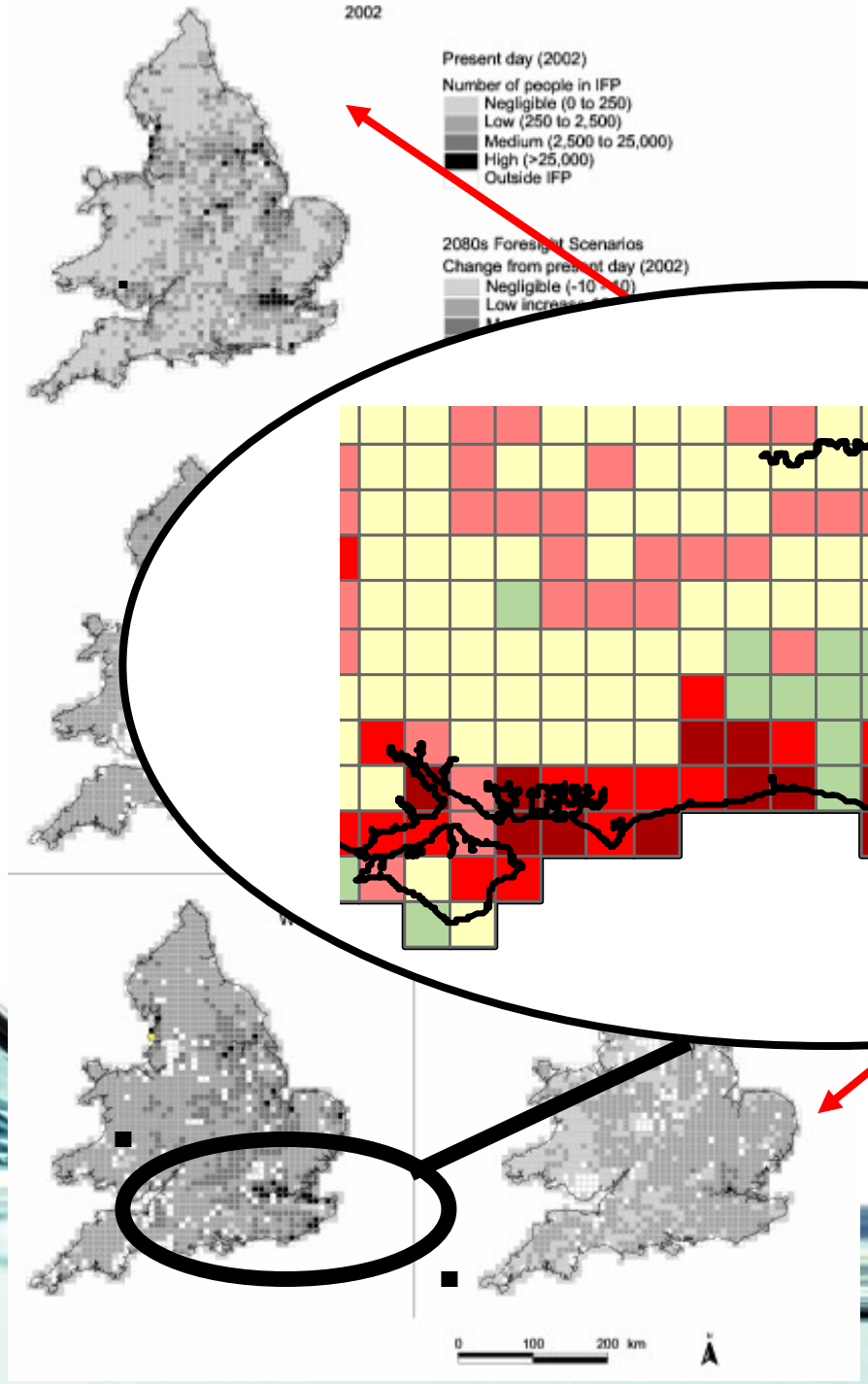
Translating drivers of change into the risk model….

Translating drivers of change into the risk model….
some examples

Representation of risk drivers in quantified analysis		
Variable used by risk model	**Explanation**	**Drivers that may be represented with this variable**
Standard of Protection (SoP) of flood defences.	The return period at which the flood defence (or where none exists the river/coastal bank) is expected to overtop significantly.	Climate change. Changes in land-use management (which may, for example, change run-off and hence river flows and water levels). Morphological change (which may, for example, also influence the conveyance of the river and hence water levels).
Condition grade of flood defences.	An indicator of the structural robustness of the defences and their likely propensity to breach when subjected to flood load.	Morphological changes. Maintenance/improvement regimes.
Location of people and properties in the floodplain.	Spatially-referenced database of domestic and commercial properties. Census data on occupancy, age etc.	Demographic changes. Urbanisation. Commercial development.

Results:

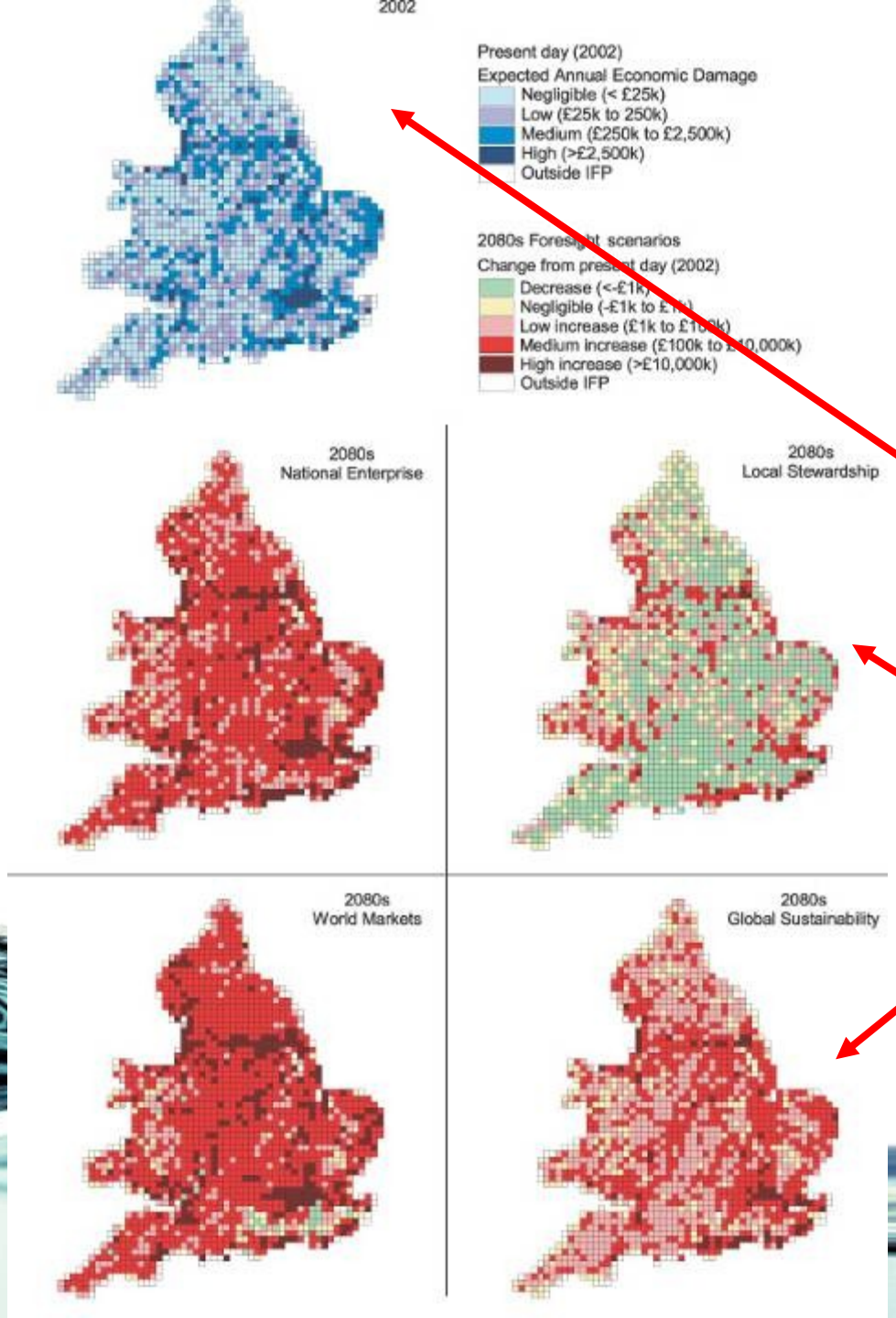
Change in probability of flooding



s for the
os: change in
risk .

Results:

Change in annual economic flood risk

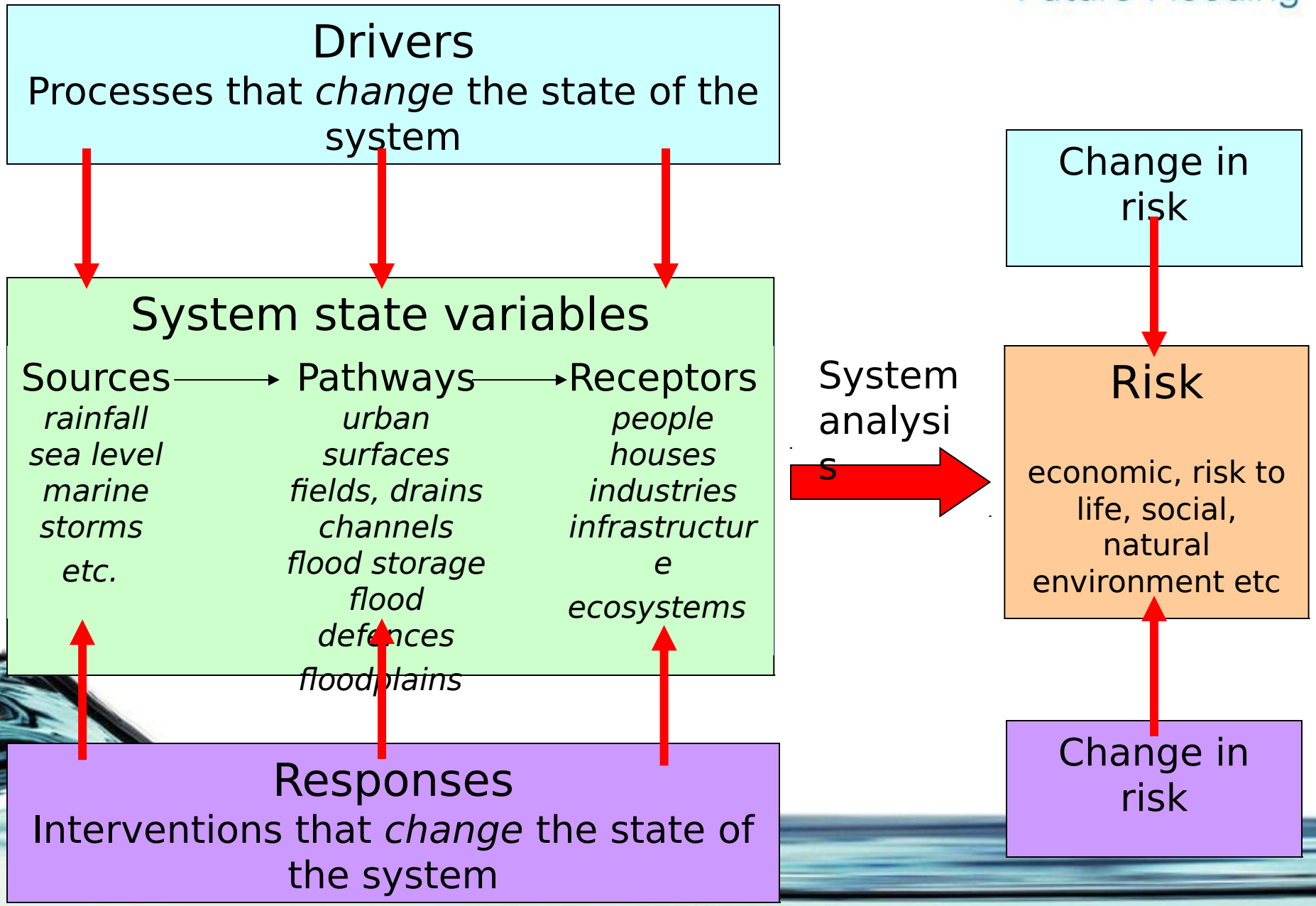


Present day values

The four scenarios for the 2080s: change in risk

SUMMARY: A very significant increase in flood risk

Risk	Location	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Fluvial and coastal erosion and flooding						
Fluvial and coastal flooding	England and Wales	1,040	20,500	15,050	1,500	4,860
Coastal erosion	England and Wales	14	126	87	51	46
Fluvial flooding only	Scotland	32	68	Not available		
Fluvial flooding only	Northern Ireland	16	32	Not available		
Intra-urban flooding						
	All UK	270	7,880	5,055	740	1,870
Total risks £ millions (rounded to the nearest £100 million)	All UK	1,400	28,600	20,200	2,300	6,800
Growth in GDP relative to present day		1.0	14.1	4.6	2.6	8.1
GDP (£ billions)		[illegible]	[illegible]	[illegible]	[illegible]	8,630
EAD as a percentage of GDP		0.13%	0.19%	0.41%	0.08%	0.08%


Drivers
Processes that *change* the state of the system
System state variables
Sources
rainfall
sea level
marine storms
etc.
Pathways
urban surfaces
fields, drains
channels
flood storage
flood defences
floodplains
Receptors
people
houses
industries
infrastructure
ecosystems
Responses
Interventions that *change* the state of the system
System analysis
Change in risk
Risk
economic, risk to life, social, natural environment etc
Change in risk

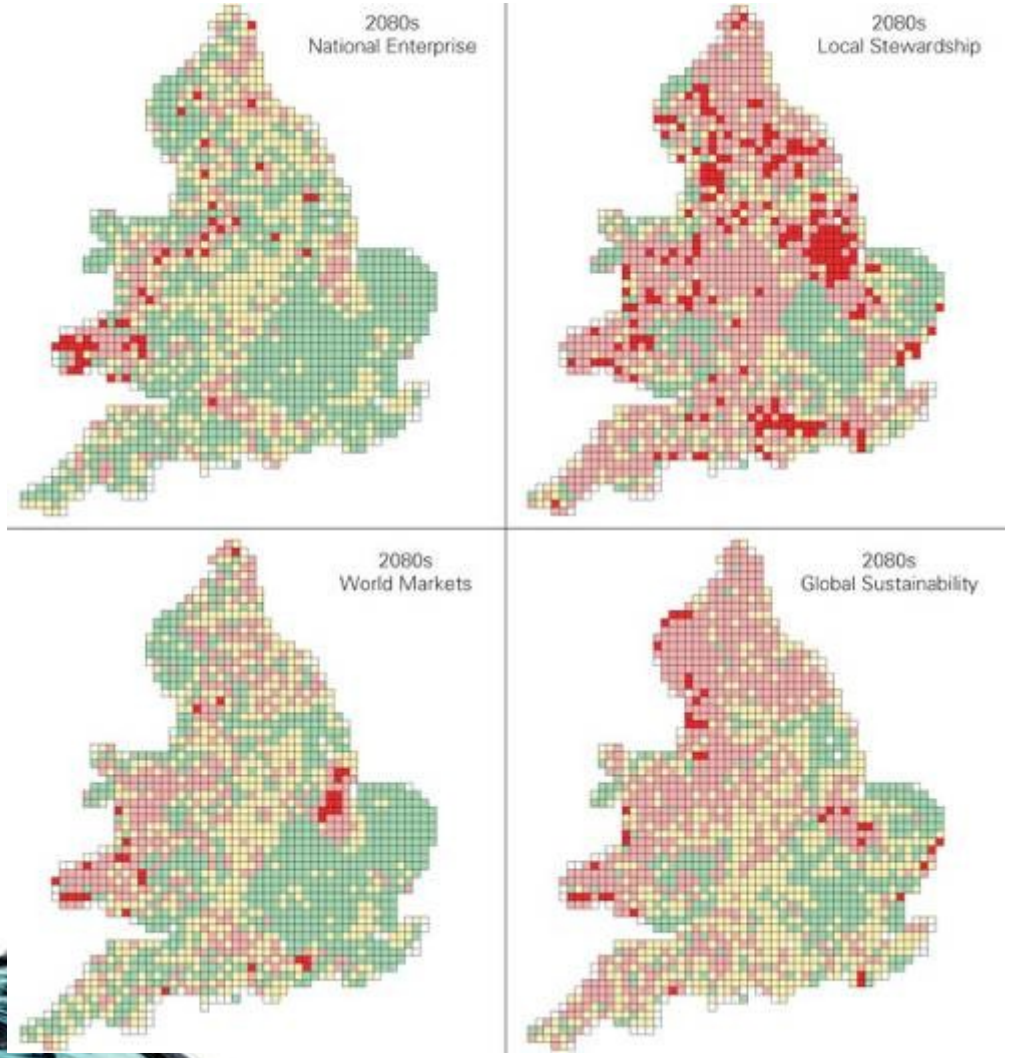
Quantified analysis of the response portfolios

Variable used by the quantified risk analysis	Response modelled	Scale of use in each flood management portfolio			
		WM	NE	LS	GS
Standard of Protection (SoP) of flood defences					
To reflect an increased or decreased protection against flooding from a range of measures.	***Managing the Rural Landscape***				
	Water Retention and Management of Infiltration into the Catchment	–	–	–	+
	Water Retention through Catchment-Storage Schemes	–	++	++	+++
	Managing Conveyance	–	–	–	++
	Managing the Urban Fabric				
	Increase Storage in Urban Areas	+	+	++	++
	Increase Infiltration in Urban Areas	–	–	–	–
	Managing Flood Events				
	Flood Fighting: Actions to Manage Flood Waters and Defences During the Event	++	++	++	++
	Engineering & Other Large Scale Interventions (Fluvial)				
	Increase Conveyance or Flow Passed Downstream	++++	+++	++	+++
	Increase Storage	++	++	+++	+++
	Flood Water Transfer	+	+	–	+
	Physical Barriers	++++	++++	+++	+++
	Realignment	+	+	++	++
	Abandonment	–	++	+++	–
	Engineering & Other Large Scale Interventions (Coastal and Estuarial)				
	Realignment of Flood Defence Infrastructure	+	+	++	+++
	Morphological Protection	+	+	+	++
	Abandonment	–	++	+++	–

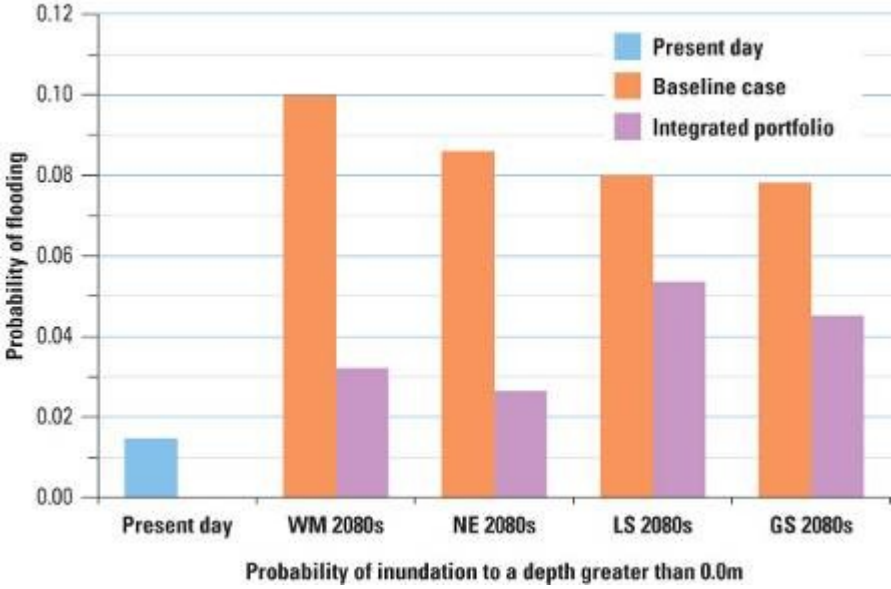
Quantified analysis of the response portfolios

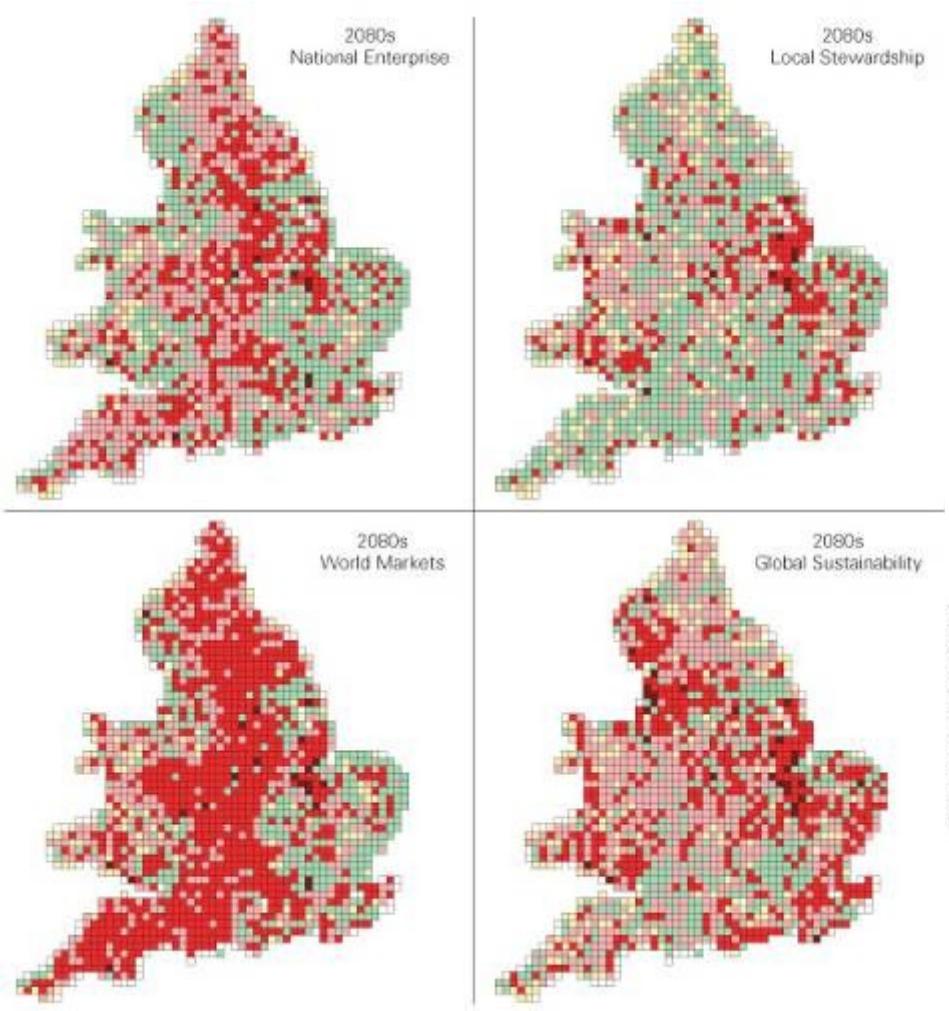
Variable used by the quantified risk analysis	Response modelled	Scale of use in each flood management portfolio			
		WM	NE	LS	GS
Location of people and property in the floodplain and flood depth-damage relationships					
To reflect a change in the number of people at high risk and likely economic damage to be incurred during a flood event.	***Managing Flood Events***				
	Pre-Event Measures	+	–	–	–
	Real-Time Forecasting and Warning	+	–	–	–
	Collective-Scale Damage-Avoidance Actions	+	+	++	++
	Individual-Scale Damage-Avoidance Actions	++	+	+++	+++
	Managing Flood Losses				
	Reduce Current Exposure to Flood Loss Through Land Use Management	–	–	+	+
	Reduce Current Exposure to Flood Loss Through Flood Proofing	++	+	++	++++
	Limit Increase in Exposure to Flood Loss Through Land Use Planning	++	+++	+++	++++
	Lessen the Health, Social and Practical Impacts of Flooding	n/c	n/c	n/c	n/c
	Abandonment	–	++	+++	–
Reduction factors					
Measures that will reduce total flood damage, e.g. flood warning and evacuation, have been reflected by factoring the estimated annual average damage	***Managing Flood Events***				
	Pre-Event Measures	+	+	+	+
	Real-Time Forecasting and Warning	++	++	++	++
	Collective-Scale Damage-Avoidance Actions	–	–	–	–
	Individual-Scale Damage-Avoidance Actions	++	+	+++	+++

Reduce Current Exposure to Flood Loss Through Flood Proofing ++ + ++ +++



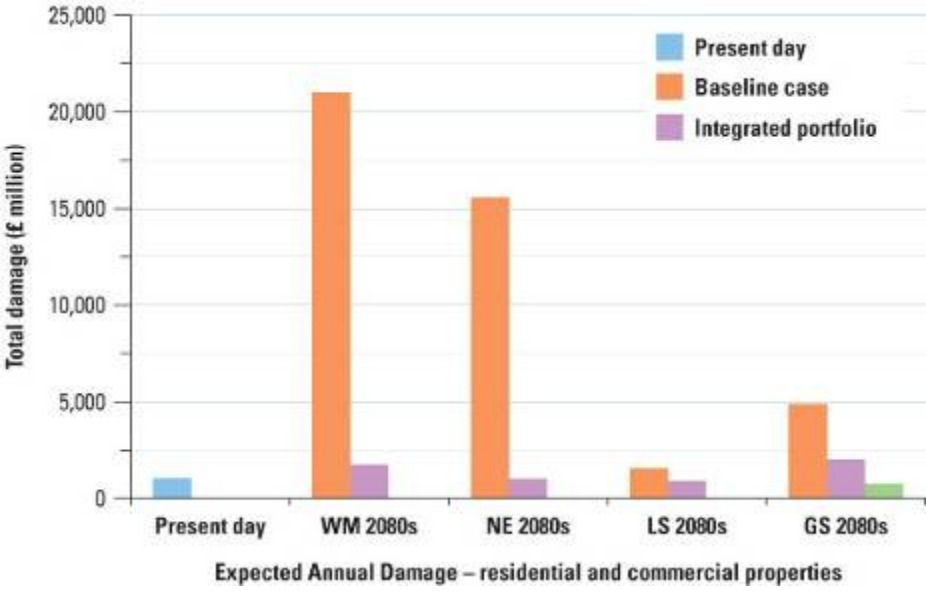
Responses:
Probability of inundation





Responses:

Expected Annual Damage



Analysis of implementation costs

Table 5.2 **Indicative costs of construction per kilometre of defence**

RASP defence type	Comments	Average total cost/kilometre (£)
Earth embankment	Typical cost	550,000
Culverts	Typical cost	2,000,000
Protected embankments and sea walls	Typical cost	2,700,000
Dunes	Management activities of planting/ fencing only, NOT replenishment	53,000
Shingle beaches	Includes the typical costs of associated structures such as groynes, breakwaters etc. where part of scheme	5,100,000

Analysis of implementation costs

Table 5.9 **Investment required to raise defences to achieve standards matched to scenarios in the 2080s following implementation of other non-structural solutions**

Region	Residual investment in defence raising (£m)			
	World Markets	National Enterprise	Local Stewardship	Global Sustainability
East Anglia	20,846	19,967	6,587	5,314
Midlands	8,106	8,570	1,263	1,940
North East	6,354	6,577	1,637	1,887
North West	3,922	4,052	1,215	1,189
Southern	13,845	13,588	3,586	4,162
South West	8,943	9,386	2,305	2,490
Thames	6,835	7,259	2,612	3,201
Wales	6,790	7,781	2,908	2,181
Total	**75,641**	**77,180**	**22,115**	**22,365**

- Only the costs of engineering measures have been estimated (excluding non-structural interventions)
- Exclude land purchase, compensation or significant environmental mitigation
- Without non-structural measures the costs roughly double

Conclusions

National-scale flood risk analysis...

- has been shown to be feasible in the UK, and is steadily improving
- yields results that are approximate, but do correspond to recent observed flood damages
- provides the basis for quantified policy analysis
- was used in the Foresight study to demonstrate that:
  - the potential for future increases in risk is considerable, and due to a combination of factors
  - application of a portfolio of measures can bring the risk down